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Cheese whey effects on surface soil hydraulic properties

G. A. Lehrsch & C. W. Robbins

Abstract. Whey, the liquid byproduct of cheese production, can improve the physical condition of sodic soils or those susceptible to erosion by increasing their aggregate stability. The effects of whey on soil hydraulic properties, however, are not known. In this experiment, we used tension infiltrometers to determine whey effects on infiltration rates of water (at suctions $\geqslant$ 30 mm of water) and unsaturated hydraulic conductivities of Ap horizons of a Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthid) after a winter wheat crop. In the summer of 1993 near Kimberly, ID, USA, liquid whey was flood-applied at either 0, 200, 400, or 800 t/ha to plots planted to wheat the previous September. At suctions of 60 and 150 mm, infiltration rates decreased linearly by about 0.7 μm/s with each additional 100 t/ha of whey applied. As whey applications increased, hydraulic conductivities at 60 mm suction increased slightly but as applications exceeded 400 t/ha decreased significantly. We concluded that summer whey applications up to 400 t/ha would not adversely affect surface hydraulic properties.

Keywords: Soil, infiltration, hydraulic conductivity, wheat, *Triticum aestivum*, whey, application to land

INTRODUCTION

It is difficult to produce crops on chemically degraded soils or on soils with adverse physical conditions. To correct some of these limitations to plant growth, inorganic amendments such as fertilizer, lime, elemental sulphur, and gypsum are often added to such soils. Organic amendments, such as sewage sludge, paper mill sludge, municipal solid waste, compost, manure, plant residues, and waste water, are also used because they add nitrogen and organic material as well as improving soil physical properties such as permeability and porosity (Robbins & Gavlak, 1989; Logan, 1992).

One such organic amendment is cheese whey, which is the water and milk solids that remain after the butterfat and most milk proteins have been removed from milk when cheese is made (Robbins, 1995). Whey is readily available at cheese production facilities. In the United States, the production of more than 2.3×10^6 t of cheese generates more than 20×10^6 t of whey annually (Robbins, 1995). Though often fed to poultry or livestock, whey is frequently considered a waste product and at times is applied to land (Watson *et al.*, 1977), nearly always at a cost to the cheese producer. Cheese whey does, however, improve the productivity of soils containing sodium (Robbins & Lehrsch, 1992; Jones *et al.*, 1993; Lehrsch *et al.*, 1994). Where whey is available at little or no cost, it is an attractive organic amendment.

Whey has significant potential as an amendment for land reclamation, particularly in the western United States where soils can be affected by relatively large amounts of sodium and/or lime. The low pH of the whey decreases soil solution pH and thus increases Ca solubility. As microorganisms decompose the lactose and proteins in the whey (Summers & Okos, 1982), they produce CO_2 and organic acids that also increase Ca solubility (Robbins, 1985). All of these processes will speed the leaching of exchangeable Na from a sodic soil profile when sufficient water is passed through the soil. Studying the aggregate stability of non-sodic soils, Lehrsch *et al.* (1993) suggested that adding soluble salts present in whey (Robbins, 1995) to the soil solution should reduce the diffuse double-layer thicknesses of clay domains, resulting in clay flocculation. This improved aggregation changes the pore size distribution, usually increasing the flux of both water and air through the soil profile (Hillel, 1982). Adding and incorporating whey lactose stimulates aerobic microbes that produce polysaccharides which stabilize aggregates (Allison, 1968). In a greenhouse study, Kelling and Peterson (1981) found that applications of 250 m^3/ha of whey or 22.4 t/ha of maize residue resulted in similar improvements in aggregation. Lehrsch *et al.* (1994) found aggregate stability to increase from 25 to 80% when 800 t/ha of acid whey, resulting from the production of creamed cheeses, were surface-applied and then incorporated into sodium-affected soils. In general, erosion decreases as aggregate stability increases (Luk, 1979). Watson *et al.* (1977) measured up to a fourfold increase in infiltration rates in a fallow, non-sodic soil about three months after a surface application of sweet whey, i.e. whey from the production of hard or cheddar-type cheeses. They attributed these increases to improved soil structure. Brown *et al.* (1996) found that whey and barley straw, placed in irrigation furrows, decreased irrigation-induced erosion and increased seasonal infiltration.

Cheese whey does, however, have disadvantages that may outweigh the advantages noted above. Since acid whey cannot be economically dehydrated (Robbins, 1995), its large volume and weight make handling troublesome. If it is surface applied without incorporation, odour control may be necessary. As with many potential amendments, transportation distances must be relatively short for whey to be economically attractive.

Problems may also occur if too much whey is applied. Large whey applications could increase root zone salinity (Sharratt *et al.*, 1962; Robbins & Lehrsch, 1992; Jones *et al.*, 1993). Excessive whey applications could also decrease infiltration rates in the short term owing to organic overloading

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(Watson *et al.*, 1977; McAuliffe *et al.*, 1982). Organic overloading in particular can make management and/or reclamation difficult. Repeated sweet whey applications of 2000 m^3/ha or more decreased ponded infiltration rates by from 13 to 67% (Watson *et al.*, 1977). McAuliffe *et al.* (1982) found saturated hydraulic conductivities to decrease by approximately 50% within two days after they applied only 350 m^3/ha of a dilute sweet whey. The hydraulic conductivities did increase, however, one to three weeks after the whey was applied.

Although the effects of whey on irrigation-induced erosion and soil physical and chemical properties have been studied (Robbins & Lehrsch, 1992; Jones *et al.*, 1993; Lehrsch *et al.*, 1994; Brown *et al.*, 1996), its effects on infiltration rates (at water suctions of 30 mm or more) or unsaturated hydraulic conductivities have received comparatively little attention. The objective of this study was to determine the effects of surface-applied whey on the hydraulic properties of surface soil horizons after a winter wheat crop.

MATERIALS AND METHODS

The experiment was conducted 2.2 km northeast of Kimberly, Idaho, on a Portneuf silt loam, previously cropped to barley. A representative Portneuf Ap horizon commonly has a CEC of 190 $mmol_c$/kg, pH (saturated paste) of 7.7, an EC of 1.1 dS/m, and SAR of 0.87. Its organic C content is approximately 9.3 g/kg and it contains 66% silt and 20% clay (USDA classification, Hillel, 1982). In September 1992, the site was levelled with a grader, subsoiled to a depth of 0.28 to 0.30 m with shanks 0.3 m apart, then roller-harrowed twice. On 15 September, wheat was planted at a row spacing of 0.18 m without fertilizer. Furrows were then formed to a depth of 0.1 m every 0.76 m on all plots. Two days after planting, owing to low soil water contents, the site was furrow-irrigated for 24 h. On 3 May 1993, we constructed earthen banks around each 11- by 15-m plot. To satisfy the wheat's transpiration demand, we used a solid-set sprinkler system to apply 65 ± 16 mm (mean ± S.D.) of water in 24 h on 25 May and, from 30 June to 1 July, 76 ± 14 mm in 28 h. This water commonly has a pH of 8.2, an EC of 0.5 dS/m, and an SAR of 0.65 (Lehrsch *et al.*, 1994).

The whey used in our study was a mixture of 75% sweet whey (from the production of hard or cheddar-type cheeses) and 25% acid whey (from the production of soft or creamed cheeses); each kg of the mixture contained 0.50 ± 0.09 g P, 16.7 ± 2.5 mmol Ca, 3.7 ± 0.8 mmol Mg, 31.1 ± 10.0 mmol Na, and 17.8 ± 2.6 mmol K. The pH was 3.5 ± 0.7, the EC was 7.8 ± 1.3 dS/m, the SAR was 6.9 ± 1.8, and the chemical oxygen demand was $57\,200 \pm 5\,500$ mg O_2/l. The whey contained approximately 6% (v/v) milk solids (primarily proteins and sugars), and had a density of 1.01 g/cm^3. At each application, 200 t/ha of whey (equivalent to a 20-mm depth or 200 m^3/ha) flowed by gravity through layflat irrigation tubing from a tank truck to a plot where it flooded across the plot surface. The control plots did not receive whey. Each plot of the low treatment (200 t/ha) received a single whey application on 8 June. Each plot of the medium treatment (400 t/ha) received a whey application on 19 May and 29 June. Each plot of the high treatment (800 t/ha) received an application on 19 May, 8 June, 29 June, and 20 July. Thus, the low treatment was a one-time application while the medium and high treatments were split applications. Wheat samples collected on 30 July and 2 August were analysed for total dry matter and grain yield, respectively.

Our intention was to study practical means of utilizing whey in the long-term. Thus, we used split applications for the medium and high rates for three reasons. First, we sought to avoid, as much as possible, organic overloading (McAuliffe *et al.*, 1982) by allowing a 3-week (or more) resting period between applications. Secondly, since whey is produced year-round, we wanted to study an application regime that would utilize whey more frequently than once per year. The application of 200 t/ha of whey two or three times during the summer was such a method. Thirdly, one-time applications of 400 t/ha (or more) of whey could have caused: (1) runoff from the Portneuf soil with its characteristic low infiltration rates; and/or (2) ponding of whey that could have led to odour problems or an anaerobic soil environment.

In August and September 1993, tension infiltrometers (Ankeny, 1992) were used to measure unconfined (three-dimensional) infiltration rates at three locations in each plot, using a slight modification of the procedure outlined by Ankeny (1992). In the bottom of irrigation furrows, where most of the whey had infiltrated, infiltration was measured without disturbing the soil surface and using large to small suctions (150 to 60 to 30 mm of water). At a water suction of 30 mm, flow occurs through pores with diameters of 1 mm or less, at a suction of 60 mm through diameters of 0.5 mm or less, and at a suction of 150 mm through diameters of 0.2 mm or less (Marshall & Holmes, 1979). After the infiltration rates had stabilized, we manually recorded reservoir water levels every 30 s for an additional 10–20 min.

Software described by Ankeny *et al.* (1993) was used to determine steady-state infiltration rates, and from these, to calculate unsaturated hydraulic conductivities. White *et al.* (1992) reviewed tension infiltrometers and the ways they can be used to study soil structural changes induced by tillage, precipitation, and biological activity.

The experimental design was a randomized complete block, with four whey application treatments, three replications, and three sub-samples per replication. Prior to performing an analysis of variance (SAS Institute Inc., 1985)[1], we examined the relationship between treatment means and standard deviations for evidence of possible heterogeneous variances among treatments. When necessary, a common logarithmic transformation was employed to obtain homogeneous variances and/or to normalize the frequency distribution of a response variable. Whey treatment means were separated using a least-squares estimation procedure (SAS Institute Inc., 1985) with a significance probability of 5%.

RESULTS AND DISCUSSION

At a water suction of 30 mm, the effect of whey upon infiltration rate was not significant at the 5% level. Examination of the data revealed, however, an infiltration rate decrease from 400 to 800 t/ha (Fig. 1a). This trend of decreasing infiltration rates with increasing whey rates was statistically significant, at higher suctions (Figs. 1b & 1c). At a suction of 60 mm, infiltration rates into irrigation furrows decreased linearly with increasing applications of whey (Fig. 1b). The rate decreased

[1]Mention of trade names, necessary to report experimental details, is for the reader's benefit and does not imply endorsement of the products by the USDA.

by about 0.75 μm/s with each additional 100 t/ha of whey applied. As the whey application increased from 400 to 800 t/ha, the infiltration rate decreased significantly ($P=0.01$), from 6.3 to 2.7 μm/s. At 800 t/ha, the soil may have been organically overloaded so that suspended solids and/or microbiological growth clogged pores at or near the soil surface, reducing infiltration rates and hydraulic conductivities (McAuliffe *et al.*, 1982). In the furrows of the 800 t/ha whey plots, some areas of microbial growth first appeared on the soil surface shortly after the third whey application on 29 June and the 76-mm irrigation one day later. These areas were visible from early July until wheat harvest. If organic overloading did not cause this 56% decrease in infiltration rate, it may have been caused by the formation of a depositional seal, possibly due to soil structural deterioration, along the furrow's sidewalls and bottom (its wetted perimeter) as a result of the four 200 t/ha whey applications. In the high-whey plots, we saw little structural breakdown, however, along the furrow wetted perimeters. The stability of macropores, as well as aggregates, influences soil hydraulic properties (Murphy *et al.*, 1993). Lehrsch *et al.* (1994) found the percentage of stable aggregates in largely undisturbed soil to drop from 64 to 46 as acid whey applications to a silt loam soil in southern Idaho increased from 500 to 1000 t/ha.

In a similar manner, at the greater water suction of 150 mm, infiltration into the bottoms of treated furrows again decreased uniformly as whey was applied (Fig. 1c). At this greater suction, the rate decreased by about 0.6 μm/s with each additional 100 t/ha of whey applied. In the medium and high whey plots, the infiltration rates, 3.5 and 1.7 μm/s, respectively, were significantly less ($P=0.015$) than the control, 6.8 μm/s. In an earlier study, Jones *et al.* (1993) found that acid whey applications of up to 1000 t/ha did not adversely affect ponded infiltration into a saline–sodic soil that was tilled after receiving whey. In our study, the soil surface was neither tilled nor disturbed in any way after whey was applied. Since tillage drastically alters soil physical and hydraulic properties, it is not surprising that the effect of whey on infiltration rates differed between the two studies.

Decreases in furrow infiltration rates at water suctions of 30 mm or more caused by large whey applications (Fig. 1) without incorporation are important for soil management. One may have a goal to maintain furrow infiltration, even under tension, at levels comparable to those of untreated conditions. If so, it may be best to annually apply no more than 400 t/ha of whey during the summer growing season to medium-textured soils in arid, semi-arid, or possibly, more humid climates.

The effects of whey on unsaturated hydraulic conductivity were similar at all three suctions, though statistically significant only at 60 mm (Fig. 2). Though the magnitude of the change in conductivity with increasing whey applications differed between suctions, the trend in the responses is shown clearly in Figure 2. As up to 400 t/ha of whey were applied, flow through pores with equivalent diameters of 0.5 mm or less increased slightly (Fig. 2). These effects on hydraulic conductivity were quite different from the effects upon infiltration (Fig. 1). The decrease in infiltration rate (Fig. 1) and the accompanying increase in hydraulic conductivity (Fig. 2) across this range of application rates are apparently due to a depositional crust effect where pores 0.5 mm or less in the crust are obstructed while similar pores below the crust are rendered more stable. At rates up to 400 t/ha, the microorganisms are probably utilizing the whey for food and, consequently, are producing polysaccharides that may be stabilizing aggregates adjacent to flow paths below the crust. As more whey was applied, however, unsaturated hydraulic conductivity exhibited a marked (and significant, $P=0.009$)

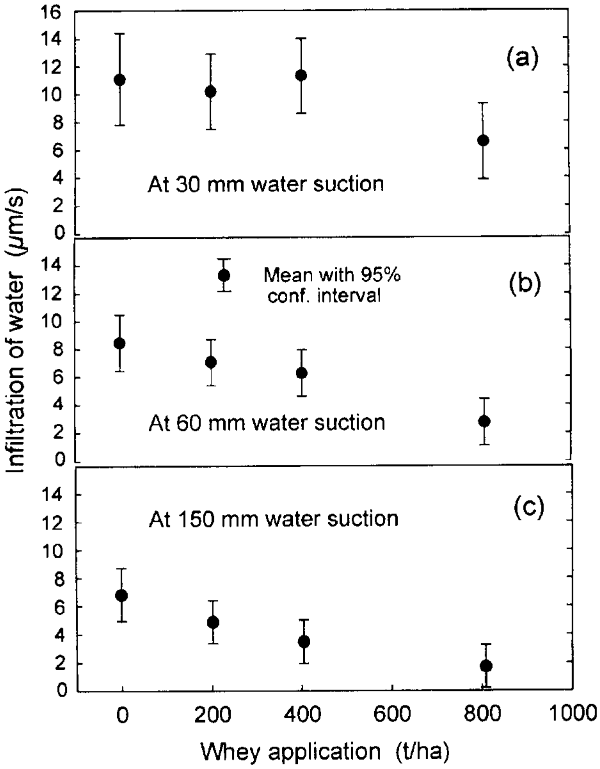

Fig. 1. Whey effects on the infiltration rate of water at suctions of 30, 60, and 150 mm of water.

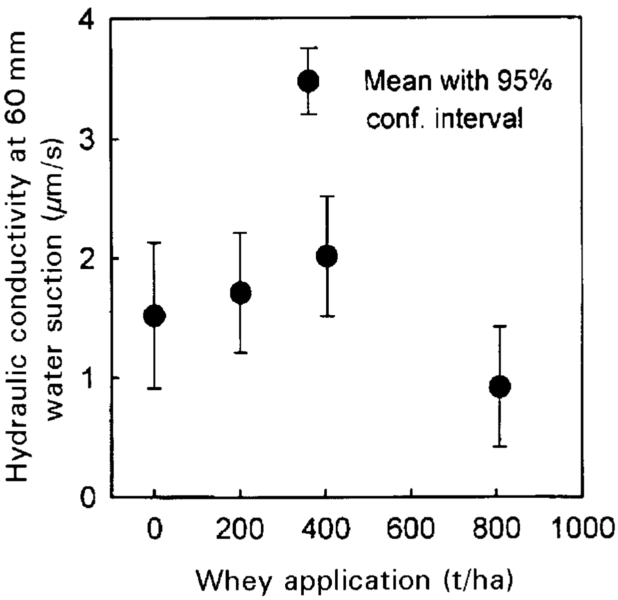

Fig. 2. Whey effects on hydraulic conductivity at a suction of 60 mm of water.

decrease from that at the 400-t/ha rate, though not from the control (Fig. 2). At higher whey rates, the system may be organically overloaded so that below the soil surface, suspended solids or the microorganisms themselves may be blocking the conducting pores, thus reducing hydraulic conductivities. In another study where excessive amounts of whey have been applied, hydraulic conductivities have decreased (McAuliffe *et al.*, 1982).

If whey is to be safely applied to soil, some questions still need to be answered. Will hydraulic properties of subsurface horizons improve or deteriorate as whey is repeatedly applied? Can whey move downward through macropores or other preferential flow channels to contaminate underlying groundwater (Peterson *et al.*, 1979; Kelling & Peterson, 1981)? How does the incorporation of whey by tillage affect the physical and hydraulic properties of surface soil? A likely increase in the aggregate stability of whey-treated soils after tillage (Lehrsch *et al.*, 1994) may offset the infiltration reductions with increasing whey applications found in this study (Fig. 1).

These findings should generally be applicable to other medium-textured soils in arid or semi-arid climates. In regions with more rainfall, maximum whey application rates to medium-textured soils should probably be less than 400 t/ha for the following reason. Applications of large volumes of liquid whey, followed quickly by rainfall, could fill pores in upper soil horizons, and possibly lead to waterlogging and aeration problems, particularly in oxygen-sensitive crops such as wheat, potato or lucerne. Similarly treated fine-textured soils, which we did not study, may also exhibit reduced rates of air exchange, due to reductions in air-filled porosity. Infiltration rates into coarse-textured soils should be little affected by whey. In such soils, however, liquid whey could move downward relatively quickly. If whey were to reach the water table under such a site, groundwater quality could be impaired because of whey's relatively high chemical oxygen demand. In coarse-textured soils with shallow water tables, large volumes of applied whey could infiltrate quickly, fill soil pores, and reduce oxygen diffusion rates.

CONCLUSIONS

As whey applications increased from 200 to 800 t/ha, infiltration rates at suctions of 60 mm or more decreased in a linear or near linear manner. At suctions of 60 and 150 mm, infiltration rates decreased by about 0.7 μm/s with each additional 100 t/ha of whey applied. As whey applications increased, hydraulic conductivities at 60 mm suction increased slightly but, as applications exceeded 400 t/ha, decreased significantly. If application rates during the summer do not greatly exceed 400 t/ha, cheese whey may be flood-applied, with no subsequent tillage, without adversely affecting hydraulic properties of surface soil.

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